Refined Soil Texture Emission Factors for Estimating PM$_{10}$

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Abstract

Airborne particulate matter of less than 10 micrometers, PM$_{10}$, is a health concern because it can bypass the body's natural defense mechanisms, settle permanently in the lungs, and impair lung function. US Environmental Protection Agency guidelines recommend that the major sources of excess PM$_{10}$ be identified and quantified. In attending to regulatory demands and public health concerns, state and regional agencies are required to develop strategies for improving existing PM$_{10}$ emissions inventories. In some areas of California, the airborne soil originating from agricultural lands and operations is the largest single source of PM$_{10}$ particles. Specifically, land preparation and wind erosion activities are major sources of soil PM$_{10}$. Predictive factors describing these processes include a soil texture variable. Current procedures rely on one soil texture value for the entire state. Thus, the estimates are error prone because they do not reflect the observed range of soil characteristics. The objectives of this study were to develop a geographic information system (GIS) methodology for generating location-specific soil texture descriptors, and to evaluate GIS-predicted PM$_{10}$ levels with measured values in agricultural areas. Selected attributes describing California soil were extracted from the US Department of Agriculture's (USDA's) STATSGO, a digital soil database, using a GIS. An area-weighted silt content was computed for each soil type. A weighted average was calculated based on the area occupied by each soil map unit in relation to the surface area. Map unit polygons delineated by silt content were intersected with a digital database of irrigated farmland to provide weighted averages relative to planted acreage. A standard USDA wind erosion equation was applied on a grid-wise basis to estimate monthly PM$_{10}$ concentrations in a major agricultural zone during a non-cropping month. Actual PM$_{10}$ measurements from the state air quality monitoring network were used for comparison.

Keywords: airborne particulate matter, PM$_{10}$, area-weighted soil texture, emission factor, wind erosion

Background

Airborne particulate matter of less than 10 micrometers (µm), PM$_{10}$, is a health concern because it can bypass the body's natural defense mechanisms and settle permanently in the lungs, impairing respiratory function. PM$_{10}$'s effects are more evident in chronic heart disease and chronic respiratory disease patients, asthmatics, elderly people, or children, but it ultimately affects everyone. High ambient concentrations of PM$_{10}$ are a

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major California air quality problem that may significantly affect public health in metropolitan areas, where federal standards for PM_{10} are frequently exceeded.

Problem Definition

US Environmental Protection Agency (EPA) guidelines recommend that major sources of excess PM_{10} be identified and quantified. In attending to regulatory demands and public health concerns, state and regional agencies are required to develop strategies to improve existing PM_{10} emission inventories.

In some areas of California, land preparation and wind erosion are major sources of primary PM_{10} emissions. Over 90% of primary PM_{10} emissions may arise from the stationary process category. Agricultural lands and operations (e.g., tillage) may account for more than 50% of those primary PM_{10} emissions (1). Predictive functions, i.e. emission factors, for estimating PM_{10} from agricultural lands include a soil texture variable. Current emission estimation procedures rely on an input variable that defines soil characteristics using one default soil texture value (18%) for the entire state. Estimates are error prone because they do not reflect the range of soil characteristics observed in California's agricultural production regions.

We suggest that estimates using these assumed average values are inadequate for local air quality management districts charged with formulating a state implementation plan. A partial solution for this inadequacy would involve improving PM_{10} emission factor data to increase the accuracy of existing inventories. Location-specific emission factors can be developed through the use of spatially disaggregated soil textural data in California.

Objective

The objective of this study was to develop a geographic information system (GIS) methodology for generating refined agricultural PM_{10} emission factors based on location-specific soil texture descriptors (i.e., silt content). The accuracy of GIS-predicted PM_{10} levels were then evaluated by comparing them with measured levels in an agricultural zone.

Methodology

EPA's AP-42 method (2) for estimating emissions from agricultural tilling, and a standard US Department of Agriculture wind erosion equation (3) were used for this study. Silt content is the required input variable for the tilling emission factor equation, whereas erodibility is the key variable for the wind erosion equation. Erodibility (susceptibility of the soil particles to detachment and transport by an erosive agent, e.g., wind) and silt content attributes of California soils were extracted from the Natural Resources Conservation Service STATSGO digital database (4) using a GIS. From STATSGO data, an area-weighted silt content was calculated for each soil type based on the area of the individual components contained therein (5). The proposed GIS methodology for analyzing these data is illustrated in Figures 1 through 5. For convenience, Kern County, California, was used to graphically illustrate the procedure.
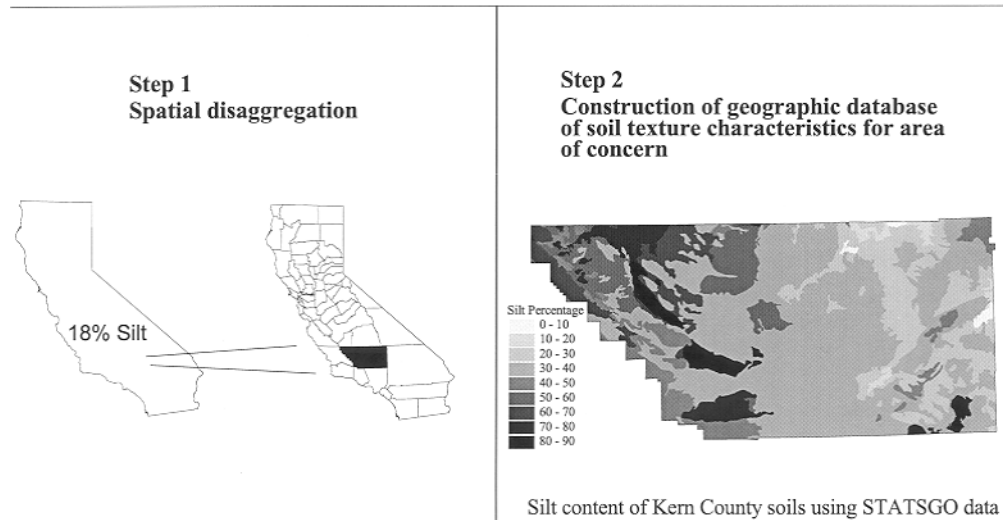
The application of this approach to the agricultural tilling emission factor is

AGRICULTURAL TILLING EMISSION FACTOR
Existing Methodology
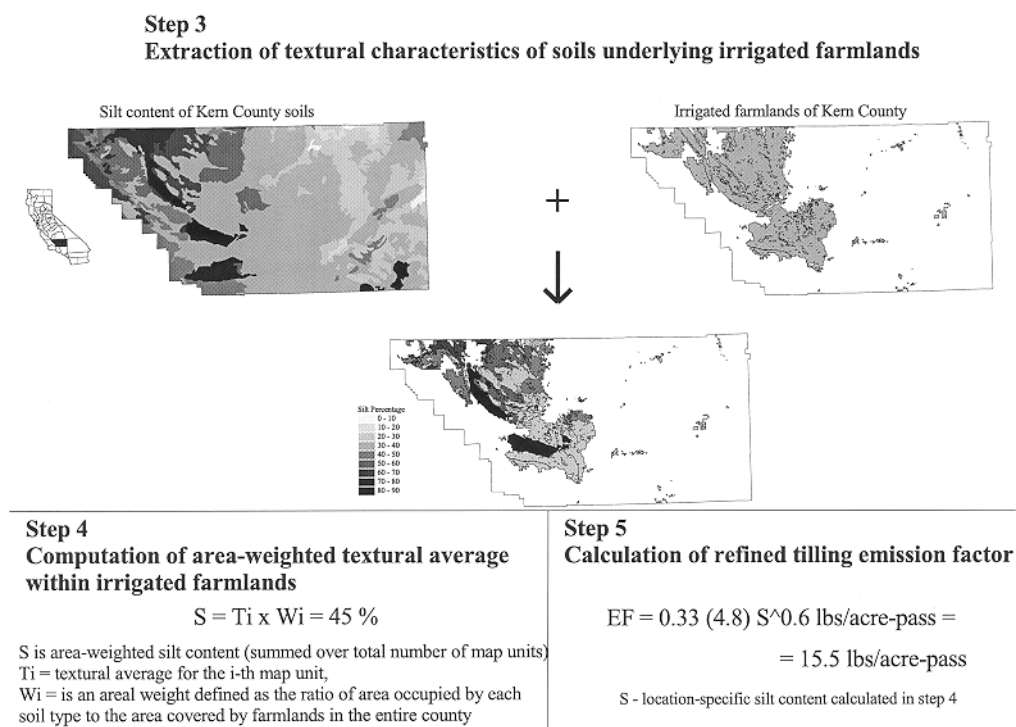EF = 0.33 (4.8) S^0.6 lbs/acre-pass = 8.95 lbs/acre-pass
S - Silt content (assumed to be 18% statewide)

Step 1
Spatial disaggregation

18% Silt

Step 2
Construction of geographic database of soil texture characteristics for area of concern

Silt Percentage
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90

Silt content of Kern County soils using STATSGO data

Figure 1 GIS methodology for refining an agricultural tilling PM$_{10}$ emission factor, steps 1 and 2. Spatial disaggregation of soil textural characteristics is graphically illustrated for Kern County, CA.

illustrated in Figures 1 and 2. First, larger areas are disaggregated into smaller geographic zones based on explicit soil characteristics (Figure 1, steps 1 and 2). The level of disaggregation in this case is from state to county. Second, location-specific soil data are developed for use as input in the emission equation. While the vast majority of crops in California are grown under irrigated conditions, irrigated farmland only constitutes a small portion of the total acreage of many counties. Therefore, countywide average soil textures may not accurately describe farmland soil textures. Irrigated farmlands in Kern County, for example, exist almost entirely in the western portion of the county (Figure 2). It follows that agriculturally relevant textural estimates may be improved if restricted to irrigated farmlands. To refine soil texture estimates in the context of farmland location, a silt content coverage was intersected with irrigated farmland at the county level (Figure 2, step 3). The silt parameter is computed as a countywide, area-weighted textural average within irrigated farmlands (Figure 2, step 4). This allows calculation of the refined tilling emission factor (Figure 2, step 5).

Figures 3, 4, and 5 depict the application of similar techniques to the windblown dust emission factor over vegetable crop fields in Kern County. In this instance, spatial disaggregation proceeds from the county level to grid cells of 2 km by 2 km (Figure 3, step 1). Soil attributes for each grid cell are extracted from the STATSGO database, and area-weighted soil erodibility is subsequently computed (Figure 3, steps 2 and 3). Location-specific soil erodibility values are then used to calculate the refined emission factor (Figure 4, step 4). Vegetable crops were assumed to be distributed uniformly

Step 3
Extraction of textural characteristics of soils underlying irrigated farmlands

Silt content of Kern County soils   Irrigated farmlands of Kern County

+

↓

Silt Percentage
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90

Step 4	Step 5
Computation of area-weighted textural average within irrigated farmlands	**Calculation of refined tilling emission factor**

$$S = Ti \times Wi = 45\,\%$$

$$EF = 0.33\,(4.8)\,S^{0.6}\ \text{lbs/acre-pass} =$$

S is area-weighted silt content (summed over total number of map units)
Ti = textural average for the i-th map unit,
Wi = is an areal weight defined as the ratio of area occupied by each
soil type to the area covered by farmlands in the entire county

$$= 15.5\ \text{lbs/acre-pass}$$

S - location-specific silt content calculated in step 4

Figure 2   GIS methodology for refining a tilling emission factor, steps 3, 4, and 5. Step 3: Extraction of location-specific textural characteristics. Step 4: Computation of a countywide silt content value within the irrigated farmlands of Kern County. Step 5: Calculation of the refined emission factor.

throughout the irrigated farmlands of Kern County, representing an estimated 12% of acreage for all crops (6). Grid-wise extraction of areal cover corresponding to irrigated farmlands is illustrated in Figure 4, step 5. Emissions are then estimated by multiplying the obtained emission factor by the acres (12% of total farmland acreage) covered by vegetable crop fields within each grid cell.
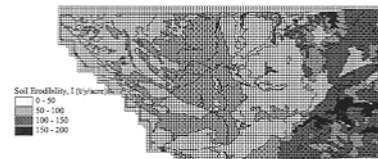
Results

Area-weighted silt content (46%) for Kern County (Figure 1, step 2) was considerably higher than the value (18%) used in previous estimates of agriculture's contribution to PM_{10}. This translates into nearly a doubling of the emission factor, from 8.95 lb/acre-pass to 15.5 lb/acre-pass. To compare GIS-predicted emission estimates (Figure 5) with actual readings, the estimates were converted into hourly average concentrations of micrograms per cubic meter ($\mu g/m^3$) by assuming a range of inversion layer altitudes (2,000 ft, 1,000 ft, 500 ft), uniform mixing within that volume of air, and by dividing by 720 hr/month. Thus, the calculated volume for comparison equals 2,000 m × 2,000 m × h, where h is inversion layer altitude (meters).

An actual average hourly PM_{10} concentration for the month of October was derived

AGRICULTURAL WINDBLOWN DUST EMISSION FACTOR
Existing Methodology

$$EF = a I K C L' V'$$

a is the portion of wind erosion losses that become suspended PM (assumed to be 0.025);
I is soil erodibility (tons/acre/year), K, C, L', V' are crop-specific and correspond, respectively,
to surface roughness, climatic factor, unsheltered field factor, and vegetative cover factor

Step 1
Spatial disaggregation

Countywide I (erodibility)

2 Km x 2 Km Grid

Location-specific I
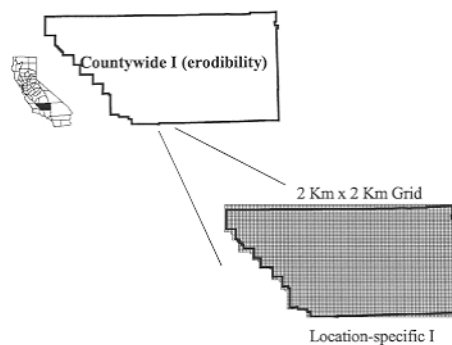
Step 2
Extraction of soil erodibility attributes for each grid cell

Soil Erodibility, I (t/y/acre)
0 - 50
50 - 100
100 - 150
150 - 200

Step 3
Computation of area-weighted soil erodibility, I (see step 4 in method for tilling emission factor)

Kernbnd.shp
Soil erodibility (t/acre)
0 - 4
4 - 8
8 - 12
12 - 16

Area-weighted erodibility for a noncropping month
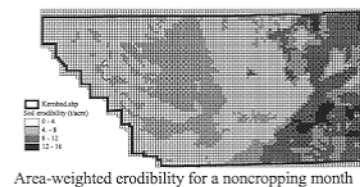
Figure 3   GIS methodology for refining an agricultural windblown dust emission factor, steps 1, 2, and 3. Step 1: Spatial disaggregation. Step 2: Extraction of location-specific soil erodibility attributes. Step 3: Computation of disaggregated soil erodibility values input into wind erosion equation.

from air quality statistics gathered at a California Air Resources Board monitoring station located in an agricultural area near Bakersfield, California. PM$_{10}$ derived from wind erosion of vegetable crop fields after harvest accounted for only a small percentage of the measured particulate mater (Table 1). Wind erosion accounted for a maximum of 3% of the PM$_{10}$, assuming a 500 ft inversion layer.

Conclusions

The results imply that the use of the 18% default value for silt content in Kern County underestimates agricultural tilling emissions. Therefore, the area-weighted silt content estimated in this study may provide a more realistic description of the magnitude and geographic distribution of PM$_{10}$ emissions from agricultural lands. These results indicate that wind erosion from idle vegetable crop fields accounts for only a small portion of airborne particulate matter present in the southern San Joaquin Valley, California, during a non-production time when there are no crops in the field.

Advantages of using the GIS methodology discussed in this paper include:

• GIS allows calculating and taking into account variations in localized factors,

Step 4
Plug I into wind erosion equation

$EF = a\,I\ K\ C\ L'\ V'$
C was calculated based on climatic
data corresponding to October, assumed to be a noncropping month.
K, L', and V' were specifically derived for vegetable crop fields

Step 5
Grid-wise extraction of areal cover corresponding to irrigated farmlands
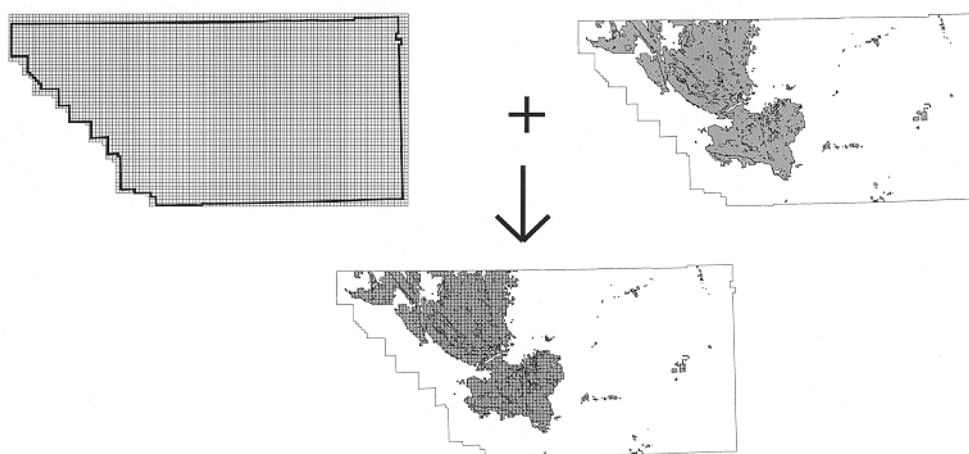
Figure 4 GIS methodology for refining an agricultural windblown dust emission factor, steps 4 and 5. Step 4: Generation of the refined emission factor. Step 5: Grid-wise extraction of acreage corresponding to farmlands.

such as soil texture. This calculation could not be performed without GIS because the computations require the manipulation of multiple layers of geographic data.

- Predictive models can be applied on a grid-wise basis to estimate local PM_{10} concentrations for comparisons with measured levels reported at monitoring stations.
- Estimates of PM_{10} levels in rural non-monitored areas of the state are possible.

Disadvantages of this GIS methodology include:

- The STATSGO digital database contained soil statistics at a resolution adequate at the county level, but it was inappropriate for analysis specific to individual farms.
- This GIS methodology cannot overcome the inherent limitations of standard emission estimation methods.
- There was a lack of digital spatial data describing the geographic location of specific crops.

Because of potential problems with STATSGO data (7), application or extrapolation of weighted textural averages should be adequately qualified to reflect the limitations of

Step 6
Estimate and map PM$_{10}$ emissions from vegetable crop fields across irrigated farmlands

Emissions = EF x Acres (vegetable crops)
Vegetable crops are assumed to distribute uniformly throughout irrigated farmlands of Kern County.
Using Kern County's Agricultural Comissioner Office data, vegetable crops were estimated to
cover 12% of acreage for all crops. This value was used to estimate vegetable crop acreage within each cell.

PM10 Emissions (lbs/month)
☐ 0 - 34
34 - 110
110 - 223
223 - 334
334 - 531
531 - 1797

Kern County PM$_{10}$ emissions from agricultural wind erosion using location-specific soil erodibility values

Figure 5   Estimation and mapping of PM$_{10}$ emissions from idle vegetable crop fields across irrigated farmlands.

Table 1   GIS-Estimated Average Hourly PM$_{10}$ Concentrations

Assumed Altitude for Inversion Layer Base (ft)	GIS-Estimated Concentration of Windblown Agricultural PM$_{10}$[a] (µg/m³)	Percentage of Total PM Measurement (45.6 µg/m³)[b] Accounted for by GIS Estimate (Agricultural PM) (%)
500	1.37	3.0
1,000	0.68	1.49
2,000	0.34	0.74

[a] Estimated average hourly readings for month of October

[b] Average hourly reading for month of October derived from measurements taken at a California Air Resources Board monitoring station near Bakersfield, California. Measurement includes PM from all sources.

PM = Particulate matter

µg/m³ = micrograms per cubic meter

the database before proposing any substantial control measures. This application of GIS to agricultural PM_{10} analysis allowed the generation of location-specific tilling and wind erosion emission factors based on published digital soil data and soil erosion models. The main aim of this study, however, was to illustrate a GIS methodology rather than produce suitable estimates for state implementations plans. Therefore, obtained values should be viewed only as approximations. Nonetheless, we believe that this technique has the potential to become a valuable tool for modeling and estimating air pollution. GIS-enhanced emission factors can lead to future improvements in estimates of particulate matter from agricultural lands in addition to other area source categories, such as road dust or construction operations.

Acknowledgments

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